A TRANSLATION INVARIANCE DENOISING ALGORITHM WITH SOFT WAVELET THRESHOLD AND ITS APPLICATION ON SIGNAL PROCESSING OF LASER INTERFEROMETER HYDROPHONE

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ABSTRACT

A Translation Invariance Denoising Algorithm with Wavelet Threshold and its Application on Signal Processing of Laser Interferometer Hydrophone is investigated. The obtained signal of Laser interferometer hydrophone exist a large number of singularity points, and the denoising algorithm of Donoho's wavelet threshold may produce the Pseudo Gibbs phenomenon on the singularity points. To eliminate the phenomenon, a denoising algorithm of wavelet threshold based on translation invariance is presented. The algorithm performs the cycle translation on the analyzed signal, and a soft threshold method is designed to shrink the wavelet coefficients of the signal and then we reconstruct the signal using the wavelet coefficients. The method can eliminate the oscillation of singularity points of the signal. Simulation experiments with the obtained data by the hydrophone show the algorithm is effectiveness.

KEYWORDS

Laser Interferometer Hydrophone; Wavelet Transformation; Threshold Denoising; Translation Invariance

1. INTRODUCTION

The Laser interferometer hydrophone can monitor water pressure, wave, surface wave and other major parameters on marine dynamical, especially in the low frequency, even in the very low frequency; it can reflect the occurrence of marine disasters, intensity and location. Compared with the piezoelectric ceramic transducer for underwater acoustic signal detection, the laser interferometer hydrophone is of high sensitivity and wide dynamic range, and it can detect extremely small vibration in water, but the hydrophone is sensitive to ocean background noise; small perturbations of ocean background noise easily populates the signal. The denoising method of Donoho's wavelet threshold is effective denoising one, but it may produce Pseudo Gibbs phenomenon on the singularity points. The obtained signal of Laser interferometer hydrophone

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exist a large number of singularity points because of the jump of the obtained measurement voltage. To suppress the phenomenon, a denoising algorithm of wavelet threshold based on translation invariance is presented in this paper. The algorithm firstly performs the cycle translation for the analyzed signal and a soft threshold method is carried out to shrink the wavelet coefficients of the signal, and then we reconstruct the signal. This denoising method can eliminate the oscillations of the singularity points. Finally, simulation experiments with the obtained data from the hydrophone show the algorithm is effectiveness.

2. **PROBLEM DESCRIPTIONS**

![Fig.1 Data from Laser Interferometer Hydrophone](image1)

**Fig.1 Data from Laser Interferometer Hydrophone**

![Fig.2 Data analysis in frequency domain](image2)

**Fig.2 Data analysis in frequency domain**

Figure 1 shows the data from Laser Interferometer Hydrophone. It shows that the obtained signal of Laser interferometer hydrophone exist a large number of singularity points because of the jump of the obtained measurement voltage. So there will be oscillations (Pseudo-Gibbs phenomenon) by some wavelet transformation. The oscillations are mainly near the singular points of the signal in denoising method based on wavelet transformation. In the neighbourhood of the singular points, the Pseudo-Gibbs phenomenon exists in the wavelet transform denoising method, so the reconstructed signal near the singular points alternately shows up or down peak, which is not inherent in the original signal, but it generated in the denoising process. Due to the localization characteristics of wavelet transformation, the oscillation amplitude is closely related to the location of the signal singularity. Therefore, we can change the order of the signals to change the positions of the singular points in order to achieve the reducing or eliminating the oscillations. For example, the wavelet transformation with the Haar wavelet does not appear Pseudo-Gibbs phenomenon when the singular point is located in \( \frac{n}{2} \) position, and in other locations, such as in \( \frac{n}{3} \), it appears a significant Pseudo-Gibbs phenomenon. So it is effective for us to make a pre-translation for the singular points which is not \( \frac{n}{2} \) position move to the \( \frac{n}{2} \) position, which can reject the generation of the Pseudo-Gibbs phenomenon, and then through the reverse translation back to the original signal so as to achieve the purpose of rejecting the Pseudo-Gibbs. For the signal \( f(t) \), \( 0 \leq t \leq N-1 \), we define \( F_n \) as \( n \)-bit translation operators \( F_n(f(t)) = f(t+n) \mod(N) \).
where \( n \) is the translation number. So \( (F_n)^{-1} = F_{-n} \). We define an operator \( T \) for signal threshold denoising process, then the eliminating oscillations process can be written as \( \tilde{f} = F_{-n}(T(F_n(f))) \) where \( \tilde{f} \) is the denoised signal by translation invariant on the original signal. When a signal contains multiple singular points, a contradiction may be generated. For a selected singular point, the translation is the best, not for others. Therefore, for a complex signal, it is difficult to obtain the best translation for all the singular points. To solve this problem, we make a cycle translation within a local range, and then make an average on obtained results. This process is written as \( \tilde{f} = \text{AVE}_{n \in D}\{F_{-n}(T(F_n(f)))\} \) where Function \( \text{AVE} \) is the average operator, the sign \( D \) is the translational range, and the max value of \( D \) is \( N \).

3. **Algorithm Descriptions**

Because the wavelet transformation is a linear transformation, we make a discrete wavelet transformation on the noisy signal \( f(k) = s(k) + n(k) \), and obtain the wavelet coefficients which are still linear components, one part of which is the coefficients \( w_{j,k} \) from \( s(k) \) and the other part is the coefficients \( v_{j,k} \) from \( n(k) \). Donoho's wavelet threshold denoising method is effective on the minimum mean square error (MSE). The basic idea of this method \(^{[1-3]}\) is as follows

1. Make the wavelet transform on the noisy signal \( f(k) \) and obtain a set of wavelet coefficients \( w_{j,k} \);

2. Make a threshold processing on \( w_{j,k} \) and obtain the estimated wavelet coefficients \( \hat{w}_{j,k} \) to make \( \|w_{j,k} - \hat{w}_{j,k}\| \) as small as possible;

3. Use \( \hat{w}_{j,k} \) to reconstruct the wavelet to obtain the estimated signal \( f(k) \) which is the denoised signal.

At this point the threshold based denoising algorithm with translation invariant wavelet is as follows

1. Make a circular translation the noisy signal;

2. Make a discrete wavelet transformation on obtained signal for each translation in order to obtain wavelet coefficients \( w_{j,k} \) on different scale;

3. Make a threshold on the obtained wavelet coefficients in order to the obtain the estimated wavelet coefficients \( \hat{w}_{j,k} \);

4. Make a reconstruction on the discrete wavelet with \( \hat{w}_{j,k} \);

5. Make a reverse cycle translation and make an average on the denoised signal.
4. NUMERICAL SIMULATIONS

Fig. 3 Donoho’s soft threshold method with db4

Fig. 4 The proposed denoising algorithm
In order to verify the effectiveness of the algorithm, we use Donoho’s soft thresholding method and signal denoising method based on circular translation for some data, respectively. Figure 3 shows the results of Donoho’s soft threshold method, which uses the wavelet base db4 wavelet. It can be seen from the figures that the denoising results of this method at signal mutation point (singular point) is unsatisfactory, which is due to the Pseudo Gibbs phenomenon. Figure 4 shows the results of the proposed denoising algorithm based on translation invariant. Denoised signal with this algorithm is smoother than the signal by db4 wavelet; especially at the point of the signal mutation. The algorithm can reject the oscillation due to the Pseudo Gibbs phenomenon. The translation in the paper is taken as \( D = \{ n : 0 \leq n < N \} \) where \( N \) is the signal length.

5. **CONCLUSIONS**

The proposed examples show the translation-invariant wavelet threshold denoising method can effectively reject the signal singularity leading to the Pseudo Gibbs phenomenon generated in the process of wavelet transformation and soft threshold denoising based on some measured data from the hydrophone.

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**REFERENCES**


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